

ICESat Mission: Heritage for ICESat-2 and DESDynl-Lidar



Ice, Cloud and land Elevation Satellite

- Launched in January 2003
- 600-km altitude, 94° inclination
- 91-day repeat ground track
- Last laser failed October 2009



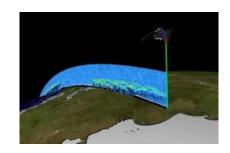
Primary Science Objective

To measure spatial and temporal variations in ice-sheet topography

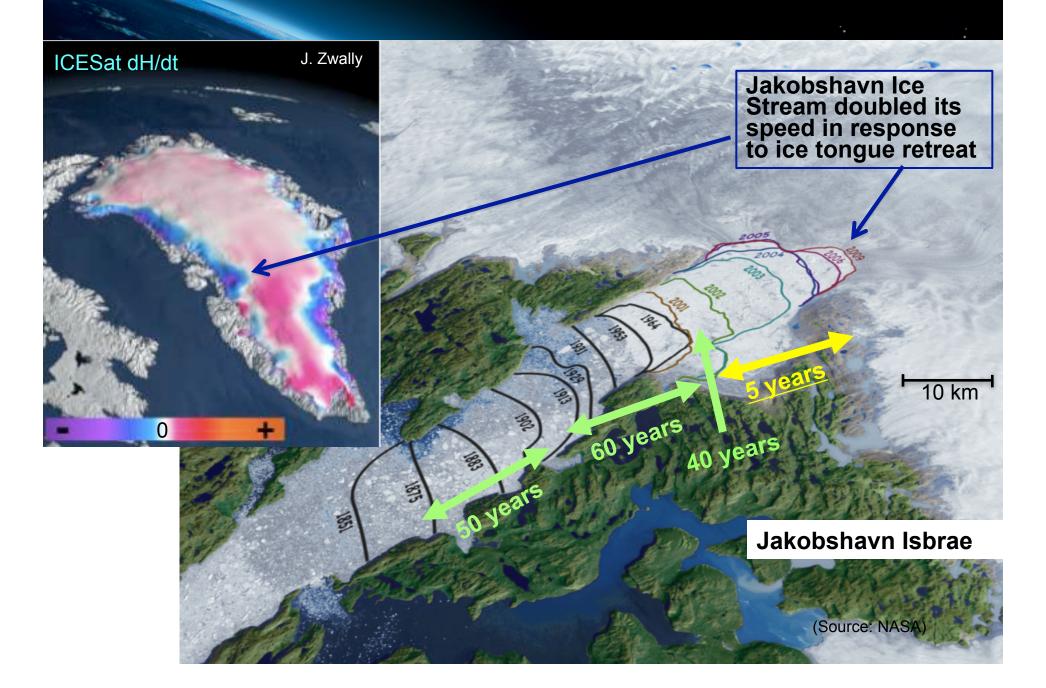


Secondary Science Objectives

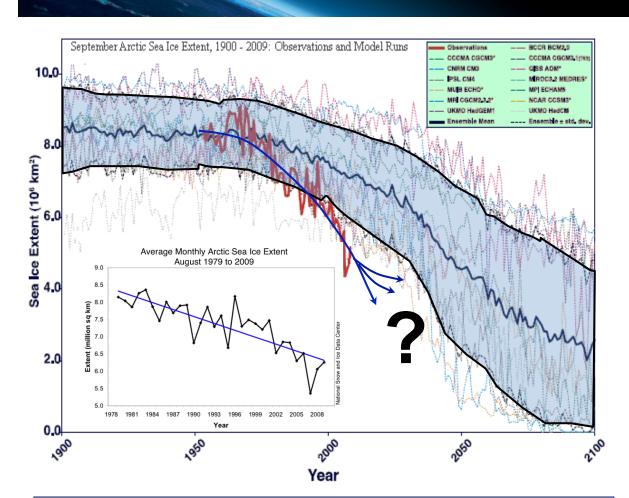
To measure cloud and aerosol properties, and to measure land-surface topography



Ice Sheets Are Changing Rapidly



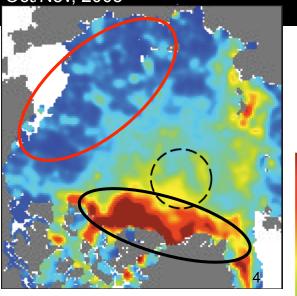
Arctic Sea Ice is Declining Rapidly

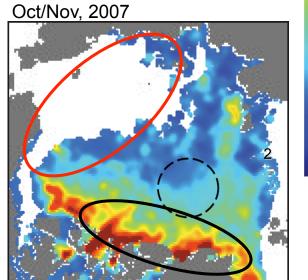


- Thickness has been a key missing variable
- Can be derived with laser altimetry

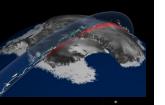
ICESat-Derived Sea Ice Thickness

Oct/Nov, 2003



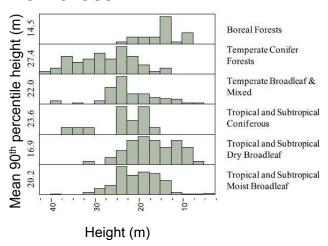


A Global Forest Canopy Height Map fron GLAS on ICESat and MODIS on Terra

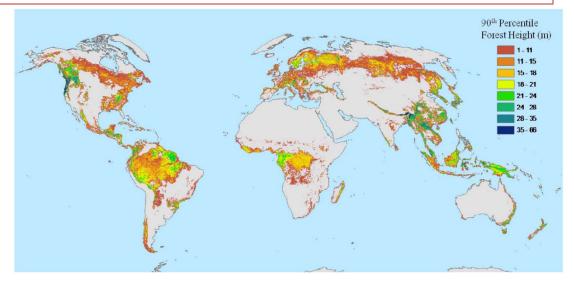


NASA-funded researchers used data from the Geoscience Laser Altimeter System (GLAS) on the ICESat mission, to create a global forest canopy height map by combining vertical information from GLAS with complete horizontal coverage imagery from MODIS. This pioneering technique indicates the degree to which improved lidar technologies can be used to provide more detailed maps of forest structure.

Distribution of heights for six broad classes of forest.

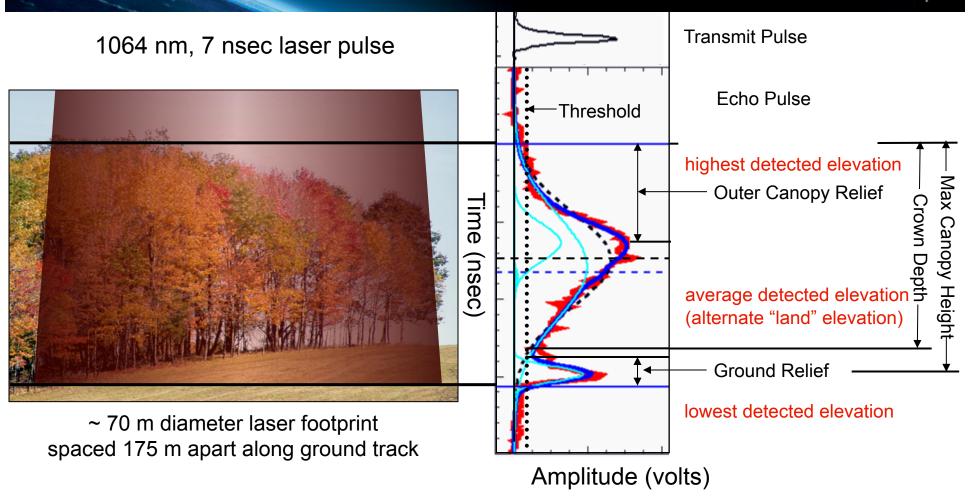


PI: Michael A. Lefsky, Colorado State University



A global map showing 90th percentile forest height – the high of the tallest trees. 90th percentile heights were used because mean heights were decreased by lower height in disturbed areas.

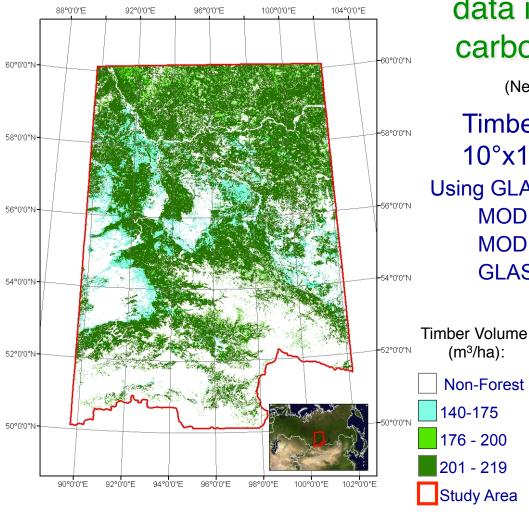
ICESat Measurement of Echo Pulse from Trees



Height Distribution of Reflected Laser Power with 15 cm Vertical Sampling

Forest Timber Volume Estimates from GLAS Lidar and MODIS Spectral Data

Central Siberia



Combined use of satellite data improves regional carbon stock estimates

(Nelson et al. 2009, RSE)

Timber Volume Map 10°x12° Study Area Using GLAS and MODIS data MODIS forest class. MODIS %tree cover. GLAS timber volume





Total Timber Volume (m³/ha):

Mean Forested Area:

- MODIS/GLAS = 202
- Shepashenko (1998) = 211

Total Study Area:

- MODIS/GLAS = 113
- Shepashenko (1998) = 109

Decadal Survey Call for ICESat-2

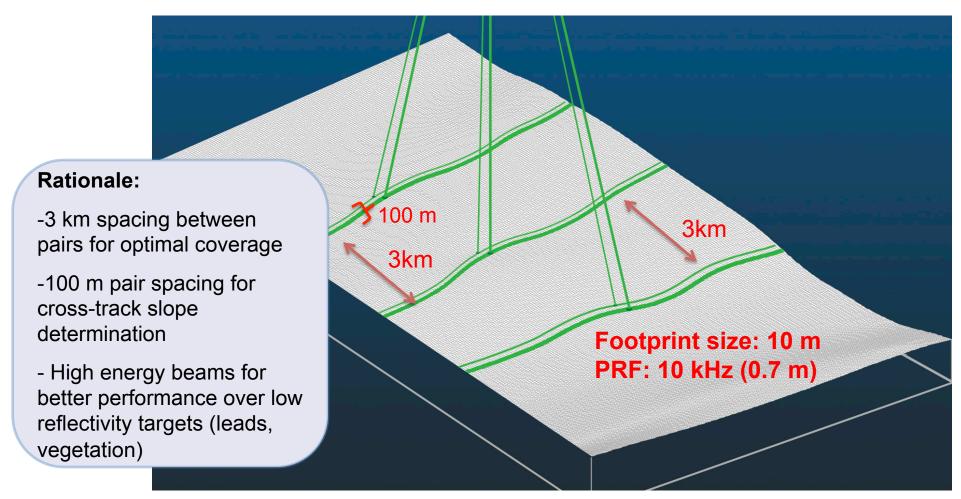
 "Given the rapidity of the change in polar sea ice and ice sheets and the limited remaining lifetime of ICESat, a critical gap would arise if the new measurements were not made prior to ... 2015" [ICESat fired its last laser pulse on Oct. 11, 2009]

ICESat 2 Scientific Objectives from Decadal Survey:

- Determine mass balance of <u>ice sheets and their contributions to</u> sea level
 - how and why is it changing, how will it change in the future?
- Repeat measurements of sea ice freeboard, enabling estimates of sea ice thickness change
 - What controls ice growth and shrinkage? what are implications for global climate of changing sea ice cover?
- Measure canopy depth to support estimating <u>changes in terrestrial</u> <u>biomass</u>
 - How much carbon is stored in above-ground biomass? (complement to DESDynl)

ICESat-2 Will Use Micro-pulse Multibeam Photon-Counting Approach.

Latest measurement concept: 3 pairs of beams, each pair with a low and a high energy beam



ICESat-2 Mission / Sensor Facts

Orbit: 600km, 91-day repeat, with monthly

sub-cycles, repeat ICESat orbit

Laser Rep. Rate: 10 kHz

Wavelength: 532 nm

Number of Beams: 6-9, with unequal energy

Along-track Sampling: 70 cm

Spot Size: 10 m

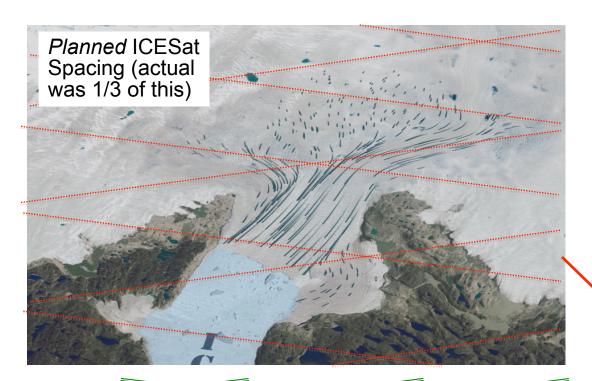
Coverage: Near global; details tbd

Standard Data Products: ??

Launch Date: 2015

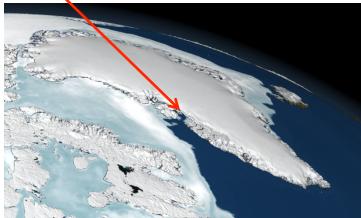
Mission Duration: 3-5 years

Website: http://icesat.gsfc.nasa.gov/icesat2

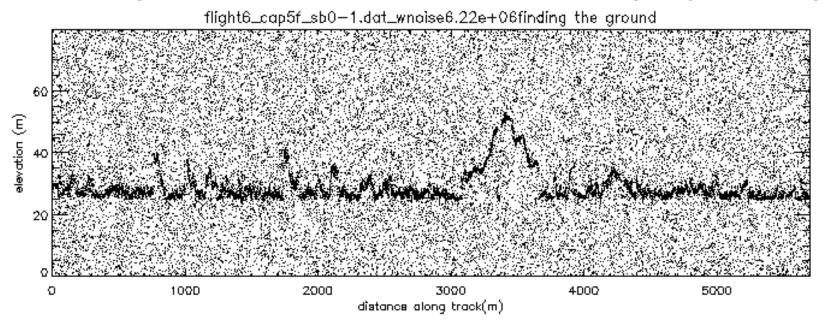


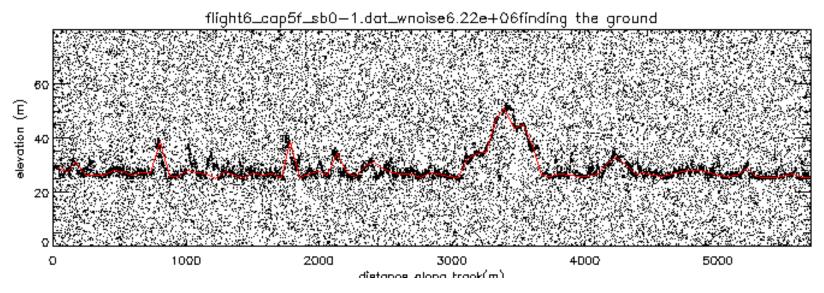
The result of this approach is an ICESat-2 sampling density that is an order of magnitude greater than was planned for the original ICESat mission



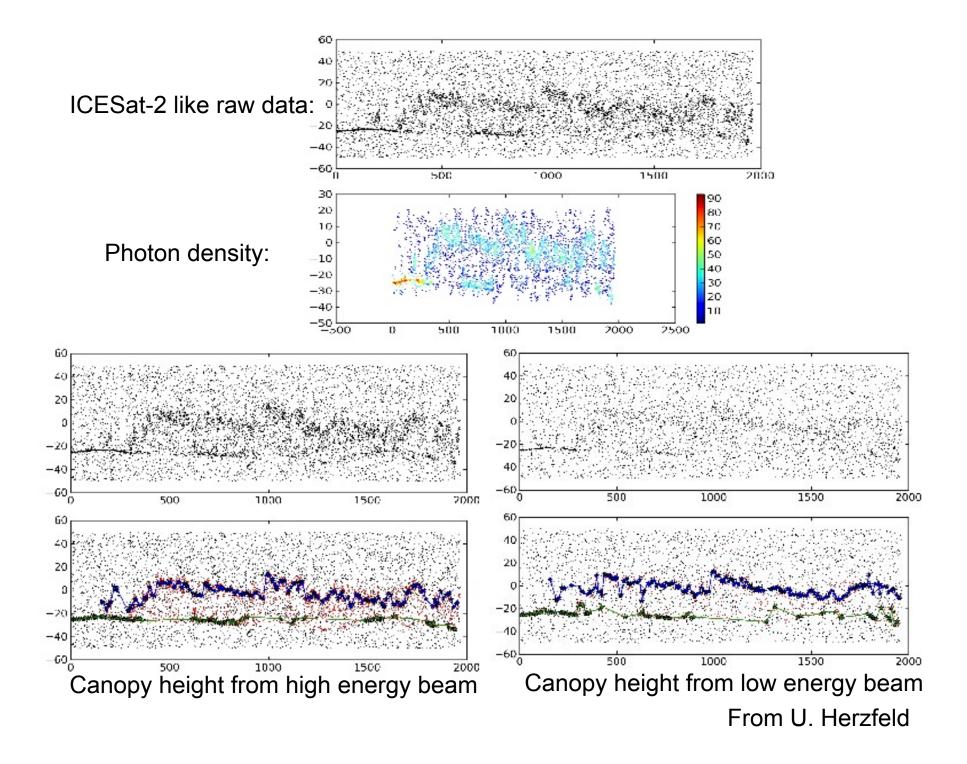


Simulated signal plus ICESat-2 realistic noise photons along rough outlet of glacier

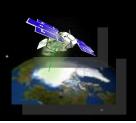




Red line shows the calculated ground elevations aggregating over 70m along track From A. Brenner

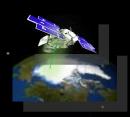


Additional Applications

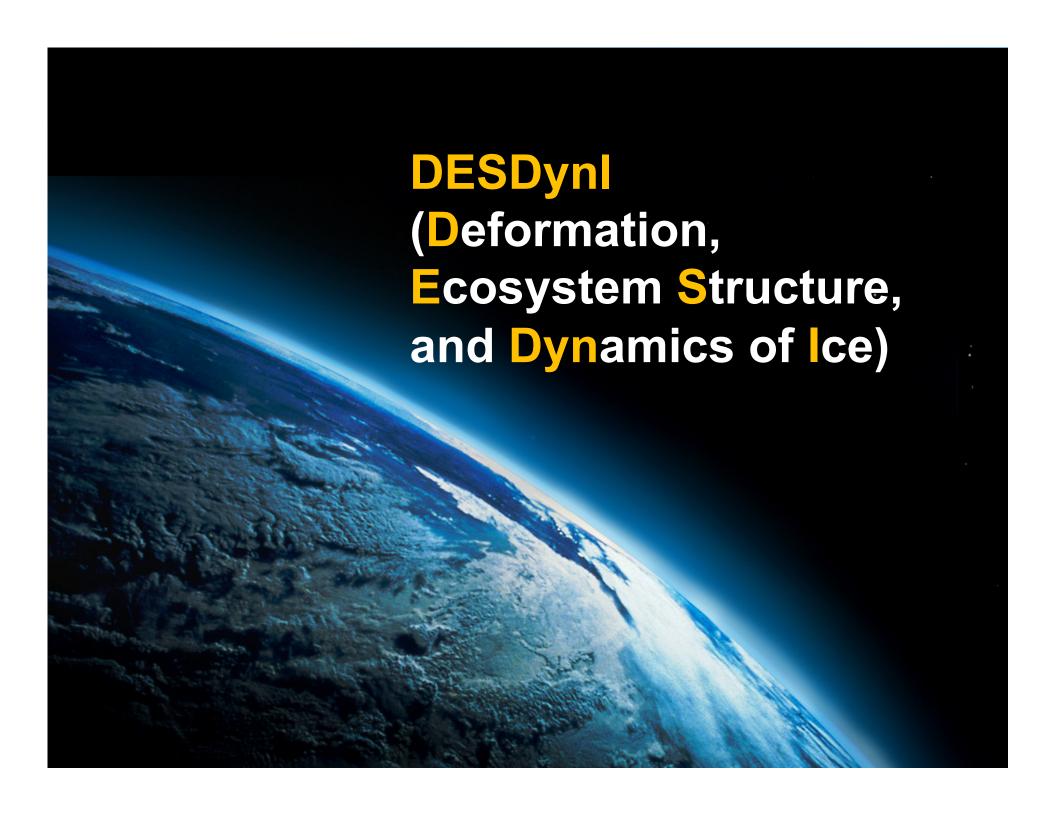


- Grounding line detection
- Subglacial lake inflation/deflation
- Basal melting of floating ice
- Tides in polar regions
- Alpine glacier elevation changes
- DEM constraints
- Clouds and aerosols
- Polar geoid
- Lake and river height
- Snow height

ICESat-2 for Conservation



- Improved forecasts of ice loss patterns, duration and sea level rise
- Estimates of biomass/carbon storage and vertical structure, at least for low density/ biomass forests
- → Utility of ICESat-2 for conservation is uncertain, but there is potential



DESDynl Science

- Recommended by the NRC Decadal Survey for near-term launch to address important scientific questions of high societal impact:
 - □ What drives the changes in ice masses and how does it relate to the climate?
 - How are Earth's carbon cycle and ecosystems changing, and what are the consequences?
 - □ How do we manage the changing landscape caused by the massive release of energy of earthquakes and volcanoes?
- ◆ Planned by NASA as one of the following 4 Decadal Survey TIER 1 Missions
 - □ SMAP
 - □ ICESat-II
 - □ DESDynI
 - □ CLARREO

Ice sheets and sea level

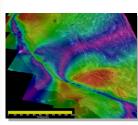
- Will there be catastrophic collapse of the major ice sheets, including Greenland and West Antarctic and, if so, how rapidly will this occur?
- What will be the time patterns of sea level rise as a result?

Changes in ecosystem structure and biomass

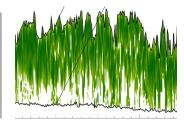
- How does climate change affect the carbon cycle?
- How does land use affect the carbon cycle and biodiversity?
- □ What are the effects of disturbance on productivity, carbon, and other ecosystem functions and services?
- What are the management opportunities for minimizing disruption in the carbon cycle?

Extreme events, including earthquakes and volcanic eruptions

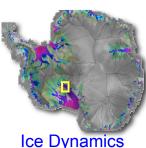
- □ Are major fault systems nearing release of stress via strong earthquakes?
- □ Can we predict the future eruptions of volcanoes?



Deformation



Biomass

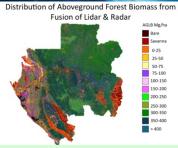


DESDynl Will Drive New Directions in Surface Change Science

- Temporal sampling reveals surface processes now poorly understood
 - Ice sheet dynamics understood by the fastest transients
 - Disturbance and recovery processes in forests (e.g. blowdowns, logging, fires and regrowth)
 - Stress transfer between faults, magma motion in volcanoes, landslide changes understood through the active events
- Need comprehensive global measurements to quantify
 - !ce sheet and sea ice behavior
 - Global forest carbon storage
 - Earthquake and volcano behavior
- Need vegetation profiling laser to characterize 3-D ecosystem structure
 - DESDynI lidar is uniquely capable of penetrating dense canopy cover with sufficient measurement density to characterize 3-D structure and estimate biomass/carbon and habitat properties

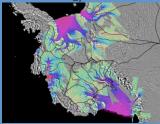
DESDynl Science to Implementation

Ecosystem Structure



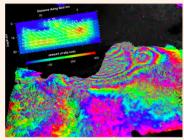
Biomass, Vegetation Structure, Effects of changing climate on habitats and CO₂, disturbance

Cryosphere

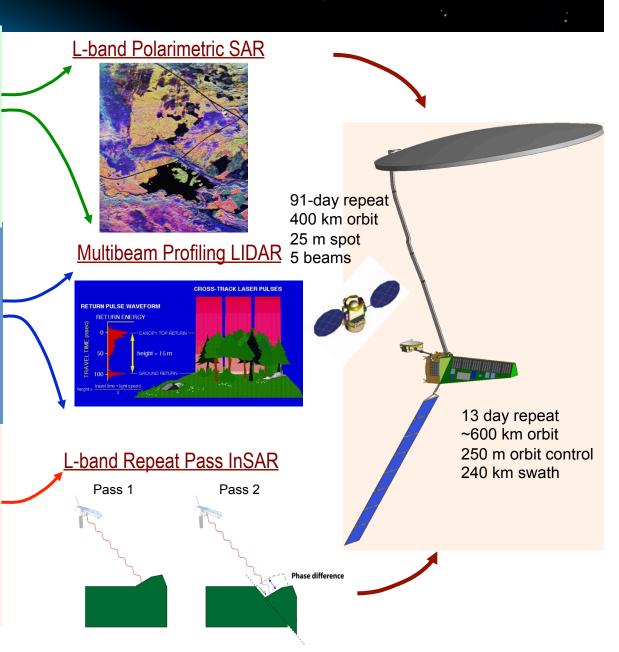


Ice velocity, thickness Response of ice sheets to climate change & sea level rise

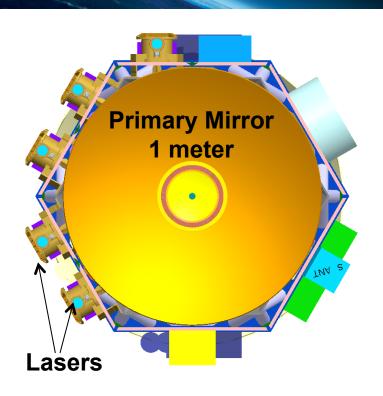
Solid Earth



Surface Deformation Geo-Hazards Water Resource Management



DESDynl Lidar Instrument Concept

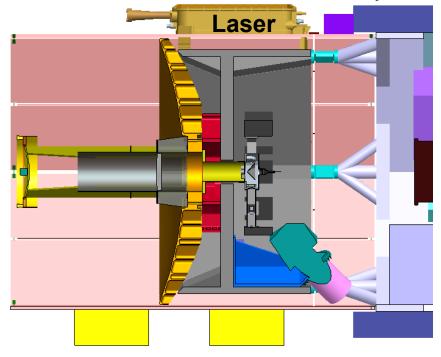


Bus hardware:

- Star trackers
- Gyros
- -S-Band Antenna
- -X-Band Antenna

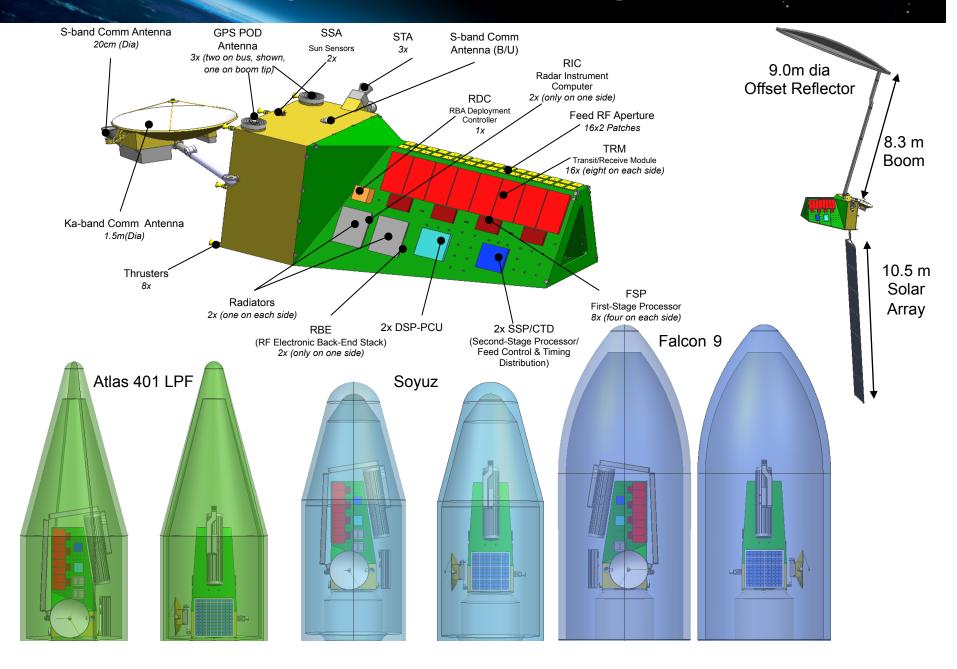
Instrument flight hardware:

- 1-meter Beryllium telescope
- 5 laser assemblies
- 5 laser electronics
- 5 detectors
- 5 digitizers
- Main Electronics Box with redundancy



Lessons learned from previous NASA laser instruments incorporated into the DESDynl laser design

DESDynl SAR Configuration



DESDynl Mission / Sensor Facts

Platforms: 2; one with quad-pol L-band radar (operated as repeat-pass interferometer), one with 5-beam profiling lidar (wavelength is 1064 nm)

Orbit: radar - 600 km, sun synchronous, dawn/dusk; lidar - 400 km, sun synchronous, dawn/dusk

Spatial Resolution: radar - 10 m; lidar - 25 m spot

Coverage: radar - global with 240 km swath; lidar - global sampling, 5 narrow beams

Temporal coverage: radar - 13-day repeat; lidar - 91-day repeat

Standard Data Products: radar to Level 1; lidar to Level 3

Data Latency: tbd

Launch Date: 2017

Mission Duration: radar - 3 years, lidar - 2 years

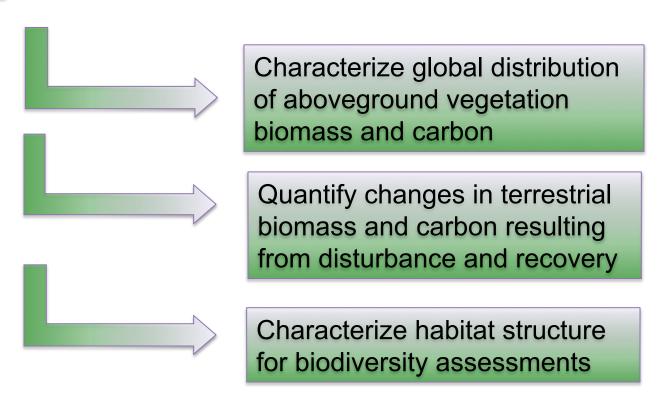
Website: http://desdyni.jpl.nasa.gov/

DESDynl Baseline Science Requirements Summary

Sainnes Objectives Messagement Benjament		In a two ways to completely
Science Objectives	Measurement Requirements	Instrument Capability
 Dynamics of Ice Ice sheet dynamics Glacier dynamics Sea ice dynamics 	 2-D velocity accurate to 1 m/yr at 100 -500 m res over ice sheets and glaciers, 3 yrs DEM topography accurate to 1 m at 1 km res over ice sheets and glaciers Elevation precise to 3 cm at 25 m profile res over sea ice Sea-ice velocity to 100-m/day at 5 km res 	 5-beam profiling lidar operated near nadir, 25 m profile res Lidar 91-day repeat orbit L-band radar operating in 13 day repeat period orbit, global accessibility, at 10 m res, continuously over mission
 Ecosystem Structure Global Biomass/Carbon Changes in Global Biomass/Carbon and Disturbance Habitat and Biodiversity 	 Canopy height and structure metrics accurate to 1 m (low slope) at 1000 m resolution in 2 yrs Biomass at 100-200 m resolution in low biomass Forest change maps, annually 	 5-beam profiling lidar operated at near nadir incidence, 25 m profile resolution Lidar 91-day repeat orbit Quad-pol L-band radar operating in 30-44° incidence angles at 10 m res, seasonally
 Deformation Tectonic processes Magmatic processes Sequestration, land-slides, aquifer change 	 2-D velocity time series accurate to 1-5 mm/yr at 10-1000 m res over active areas, 3 yrs Weekly target sampling, equatorial 	 L-band radar, 13 day repeat period orbit Global accessibility Weekly target sampling, equatorial 10 m resolution All continuously over mission

Ecosystem Structure: Primary Goal and Science Objectives

Characterize the effects of changing climate and land use on terrestrial carbon cycle, atmospheric CO₂, and species habitats

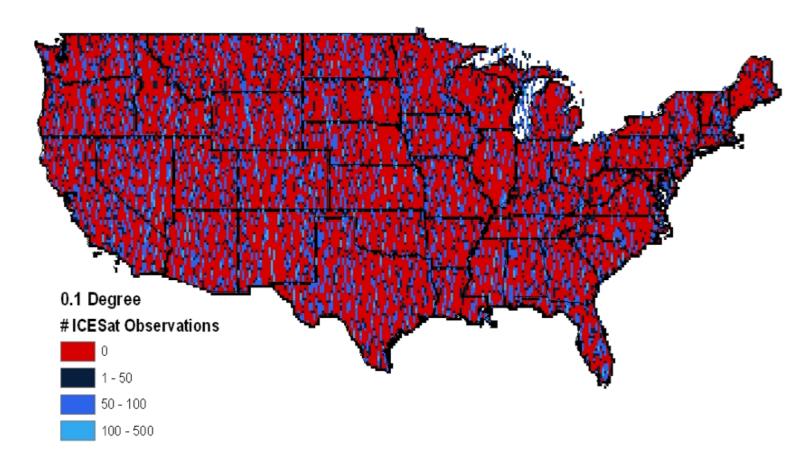


Ecosystem Structure Baseline Requirements

Measurement	Requirements	Coverage
Aboveground Woody Biomass (High Density)	< the greater of 10 MgC/ha or 20%, capped at 25 MgC/ ha Resolution: 1 km resolution	Lidar, 1 map
Aboveground Woody Biomass (Low Density)	< 10 MgC/ha When biomass is < 40 MgC/ha Resolution: 100 m	Radar, Seasonally
Aboveground Woody Biomass Disturbance	50% change in biomass	Radar, Quad-pol, Yearly
Canopy Height Profiles	Resolution: 25 m Along-track Posting: 30 m Vertical resolution: 1 m	Lidar 98.5% canopy cover

DESDynl Enables Global Carbon Mapping

- DESDynI fills the entire map at 0.1 km 1 km resolution
 - 40 50x more lidar data than existing space-based data set



Current Plans for DESDynl Science Data Products

The DESDynl project will process radar data only to L1 (Single Look Complex Imagery)

The DESDynl project will process lidar data to L3 (gridded height/biomass)

The DESDynl project will deliver all these data to the NASA archive

Higher level algorithms for radar or lidar-radar fusion will be developed only for science team cal/val activities

DESDynl Science Product Potentials

The DESDynl Mission will allow a wide range of products for:

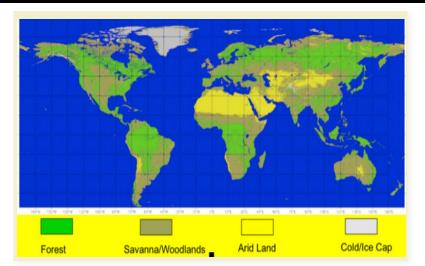
Global Ice

Global Biomass/Carbon & Biodiversity

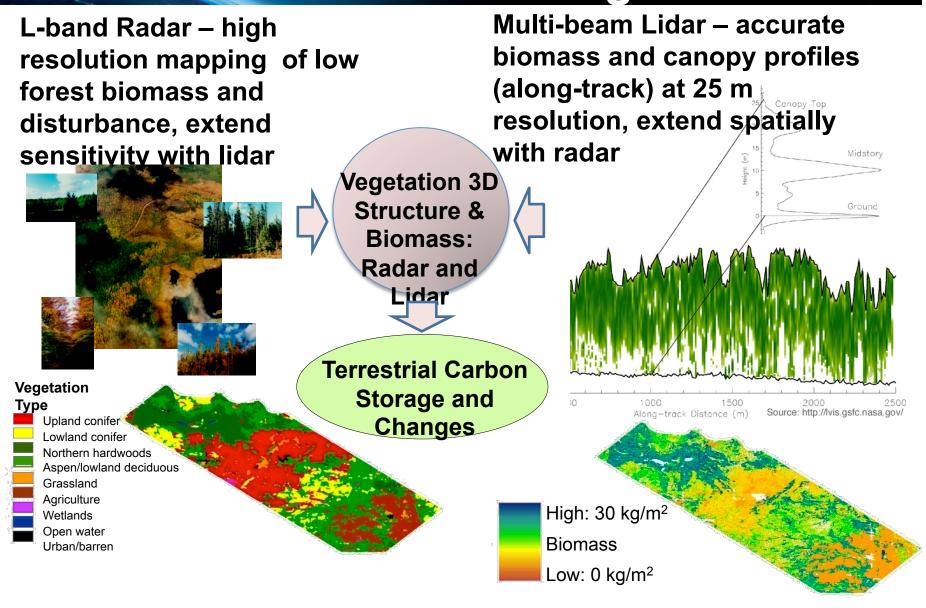
Tectonic and Volcanic Geohazards

Some Product Characteristics:

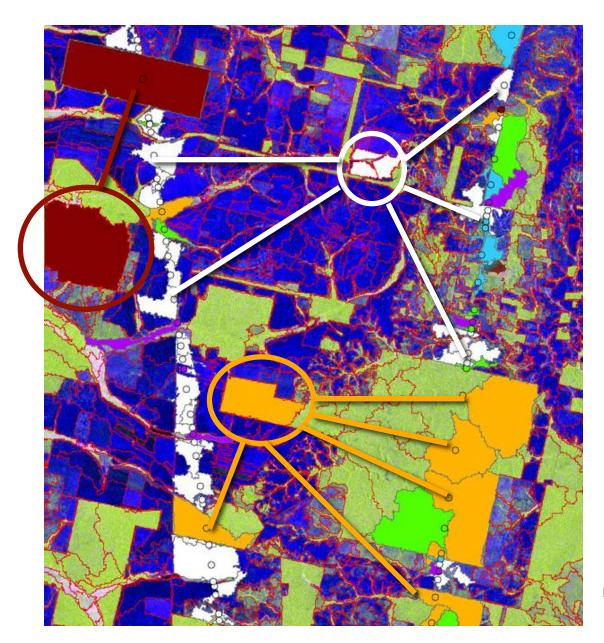
- 2-D deformation maps of ice sheets
 - Complete coverage yearly, 100 1000 m resolution, 2- 5 m /yr accuracy
- 2-D sea-ice motion at both poles
 - Weekly polar coverage, with some gaps, 5-km resolution, 100 m / day accuracy
- Biomass and biomass change
 - Global coverage yearly, 100-1000 m resolution, accuracy 20-30%
- 3-D habitat structure and biodiversity assessments
- 2-D deformation maps of Earth's most severe geohazards
 - Biweekly to yearly over Earth's deforming margins, 20 100 m resolution, accuracy from mm – cm / yr
- Sea-ice thickness
 - Monthly-yearly polar coverage, 25 km resolution, better than 60 cm accuracy



for Aboveground Biomass and Carbon Storage



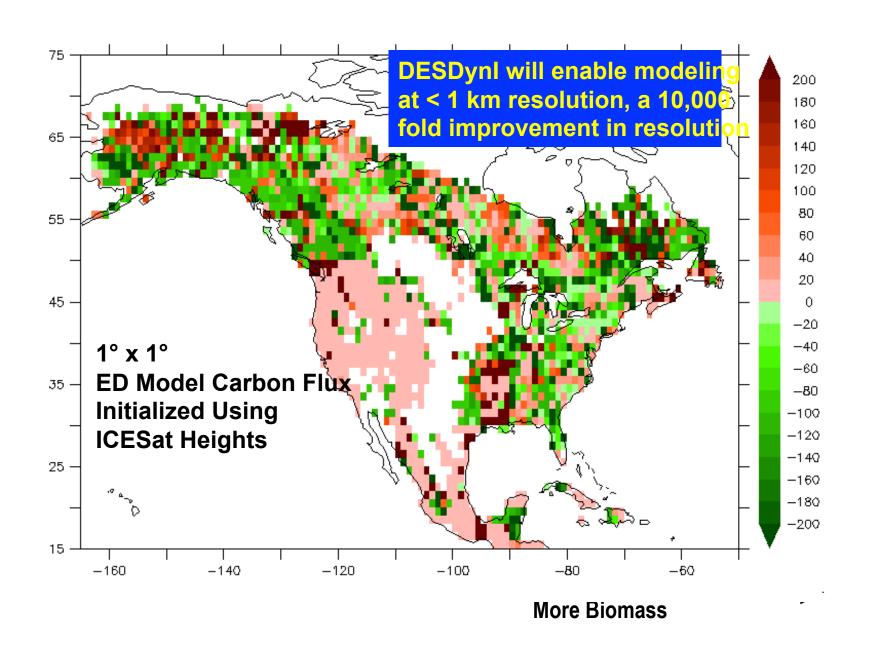
Ecosystem Structure: Radar-Lidar Fusion Approach



- 1. RADAR mosaic
- 2. LIDAR track
- 3. Segmentation (could include historic multisource data)
- 4. Generate LIDAR Segment Means
- 5. Map Segments
- 6. Predict Unmapped Segments from Models:
 - statistical &
 - location-based
- 7. Repeat with every new acquisitions

Kellndorfer J., 2010

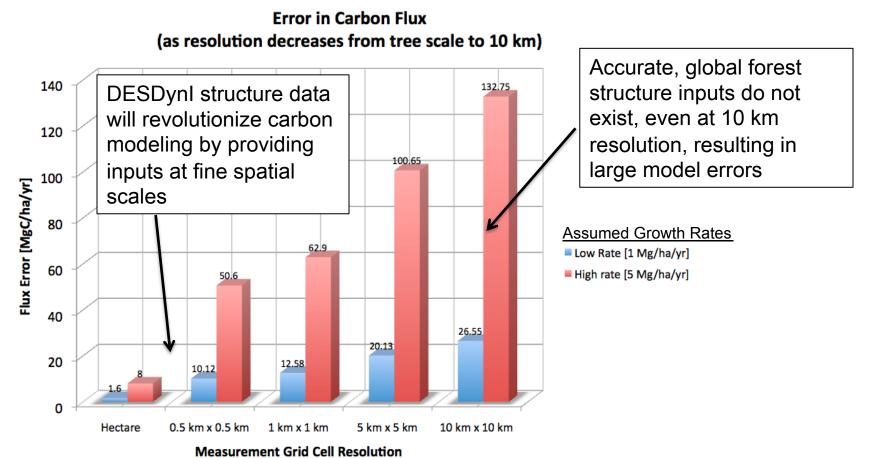
Carbon Flux From Ecosystem Modeling



DESDynl Enables Global Carbon Modeling

Carbon model data and modeling scales must be near the scale of disturbance and environmental gradients (about 1 – 10 ha)

- Coarse forest structure inputs in carbon models produce vastly inaccurate fluxes compared to DESDynl measurement scales



Habitat and Vegetation Structure

Generalist vs. Specialist

★ Many appear to have structural preferences

Birds

- ★ Most frequently studied with respect to vegetation structure and habitat preference
- **→** About one-third of the total number of studies in the literature.

Other Taxa

★ Mammals, primates, reptiles, amphibians and arthropods / insects.



Habitat Example

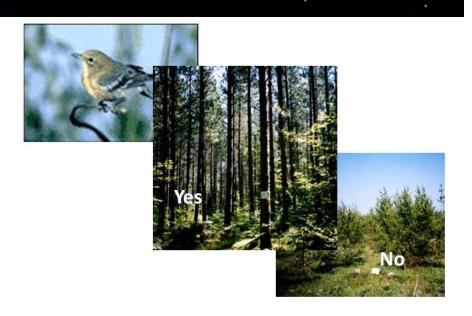
Pine Warbler Habitat:

- + Closed canopy forest

 + Uneven or broken canopies
- + Trees older than 30 years
- + Overstory taller than 30 ft
- + Well-developed underlayer
- + Large patch sizes (non-fragmented)
- Upland pine species

DESDynl Variables:

- + Canopy cover
- + Biomass (age-height-density)
- + Height
- + Canopy vertical profile
- + Patch size and shape



Example (right): Habitat for pine warbler in the Great Lakes Region is tall, dense (high biomass) pine, but not short sparse pine; also require large patch sizes (Bergen et al., 2007)

Source: USFS data base of habitat requirements compiled₃₄ from field studies

Biodiversity Example

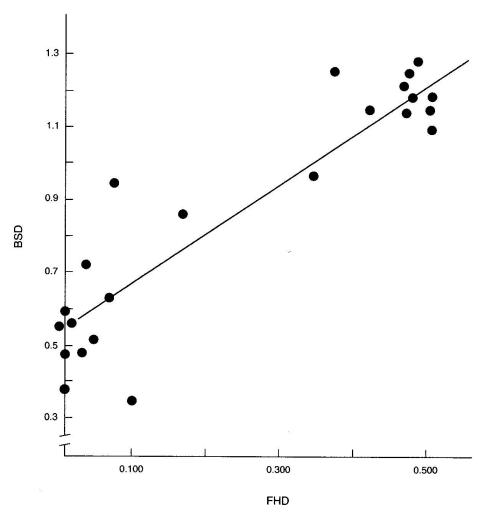
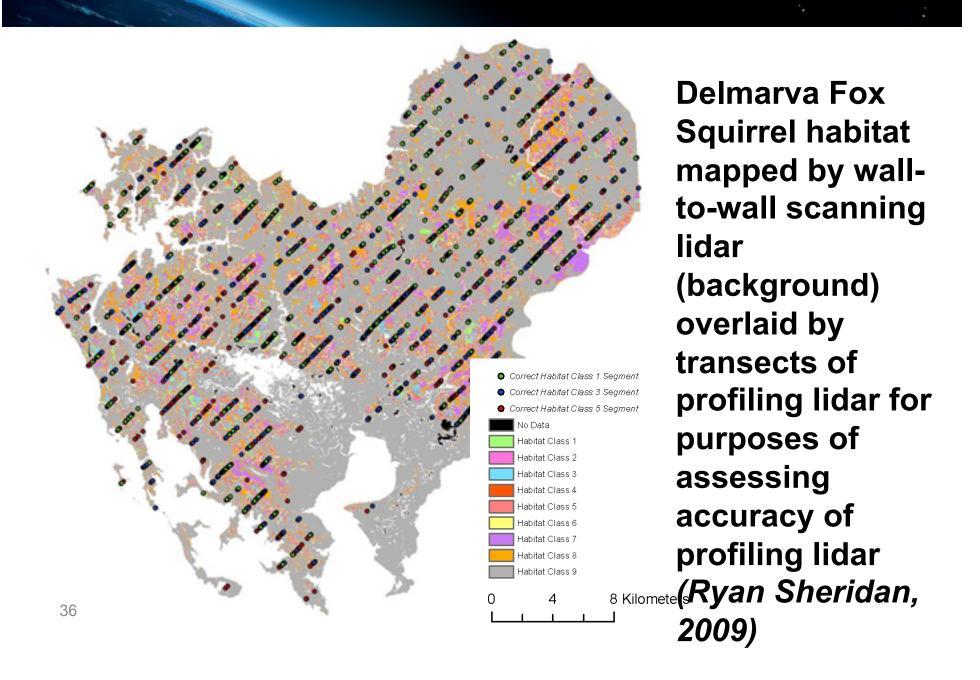


Figure 3.1. Foliage height diversity (FHD) versus bird species diversity (BSD). • represent the study sites. (Reproduced from Willson 1974 [fig. 1], by permission of the Ecological Society of America)

Relationships with Height Vertical Profile:

Foliage height diversity (FHD) vs. bird species diversity (BSD) (Wilson, 1974)

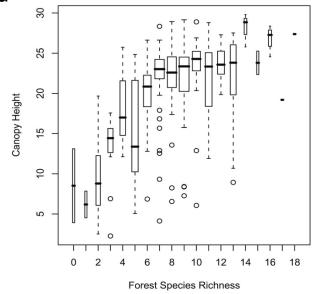
Lidar Habitat Mapping Comparison

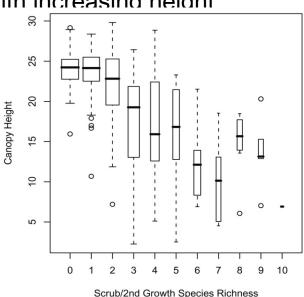


Lidar and Avian Biodiversity

Relationships of avian biodiversity with height & vertical canopy distribution

- → Box plots show range of response variable (species richness) values relative to key habitat predictor variables for A) forest species, and B) scrub species.
- → Predictor variables were derived from airborne LVIS full waveform LiDAR at a 7 km altitude with a 12 m footprint diameter. Each box shows the median (horizontal line), quartiles (upper and lower extent of box) and range (dashed vertical lines) within the predictor variables.
- ★ Forest bird richness increased linearly with height (and vertical complexity)
- → Shrub bird species richness decreased with increasing height





Goetz et al., 2007

DESDynl Enables Biodiversity & Habitat Studies

DESDynl provides the first global data set of detailed canopy structure

